Title: Loss of oysters as a result of the *Deepwater Horizon* Oil Spill degrades nearshore ecosystems and disrupts facilitation between oysters and marshes

Technical Memorandum

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Abstract: Nearshore marine ecosystems are among the most productive and threatened areas in the world. The input of terrestrial and freshwater derived nutrients into shallow-water environments where marine fauna and flora flourish results in extraordinarily high biological productivity; however, these ecosystems also serve as receiving areas for pollutants released into oceanic and riverine waters. The *Deepwater Horizon* explosion and well blowout in 2010 resulted in oiling of hundreds of kilometers of shoreline in the northcentral Gulf of Mexico. Large quantities of oil flowed into estuaries and coated coastal wetlands and beaches. In response, onsite environmental cleanup activities occurred in many of these areas. Both oiling and onsite response activities are associated with degradation of nearshore habitats. As part of the *Deepwater Horizon* Oil Spill Natural Resource Damage Assessment (NRDA), we examined the impact of shoreline oiling on oysters (*Crassostrea virginica*) that occur near marsh edge at 187 sites in Louisiana and Mississippi Sound in 2013. Marshes that were heavily and persistently oiled had 77% less oyster habitat than areas where oil was not observed, which translates to an estimated 320 m^2 of oyster habitat lost at each heavily, persistently oiled site. Oyster habitat near marshes characterized by more modest levels of oiling was 33% less than areas where no oil was observed. Similarly, the number of sites without any oyster habitat was higher in heavily and persistently oiled areas compared to areas where no oil was observed (56% vs. 24%). The consequences of this loss are substantial and include loss of essential fish habitat, reduced nutrient cycling and decreased erosion buffering. For a subset of the sites where erosion rate was also measured between 2010 and 2013 (n = 74), shoreline loss was more than twice as high (2.9 vs. 1.3 m yr^{-1}) in areas lacking oyster cover.

Introduction

An important sub-population of oysters (*Crassostrea virginica*) inhabits the nearshore zone fringing the marsh edge, forming emergent reefs or smaller hummocks. These nearshore oysters, like their subtidal counterparts, play an important ecological role through their filtration activities with critical benefits for nutrient cycling. Oysters remove sediments, phytoplankton, and detrital particles, potentially reducing turbidity and improving water quality (Dame and Patten 1981). Because they are not harvested, they provide a stable source of larvae to oysters in deeper waters (Westerink 2015). The complex habitat formed by the gregarious settlement of oysters also provides critical refuge for benthic invertebrates as well as fishes and mobile crustaceans (Meyer and Townsend 2000, Peterson, Grabowski and Powers 2003, Coen et al. 2007). Nearshore oyster reefs can also reduce erosion and stabilize coastal shorelines through sediment trapping and accretion and adding hard substrate adjacent to marsh edges (Meyer, Townsend and Thayer 1997, Piazza, Banks and La Peyre 2005, Scyphers et al. 2011).

Methods

Oyster habitat adjacent to emergent salt marsh (hereafter referred to as fringing or intertidal oysters) was surveyed in the northcentral Gulf of Mexico (between Terrebonne Bay, LA and Mississippi Sound, AL) to evaluate the distribution of fringing oysters as a function of shoreline oiling or response activities following the DWH Oil Spill. Sites (200 m long stretches of shoreline) were mapped to estimate oyster cover (as indicated by presence of shell substrate). Where fringing oysters were detected, sites were sampled for oyster density (number of oysters m^{-2}) and size frequency. Sampling occurred between February 14 and April 26, 2013.

Site Selection

Oyster sampling locations were selected from a large sampling universe of 2,779 sites assessed in 2010 (pre-assessment sites) along the coastline of the northern Gulf of Mexico between Rollover Lake, LA to Apalachee Bay, FL. Based on repeated observations by Response surveys (Shoreline Cleanup and Assessment Technique (SCAT)) and NRDA teams, shorelines along the northern Gulf of Mexico were evaluated and assigned to one of five shoreline oil exposure classes, each describing a particular pattern of oiling over time (Nixon et al. 2015). For vegetated shorelines, these classes included “heavy persistent oiling” (where heavy or moderate oiling was repeatedly observed over a period of 12 or more weeks between April 2010 and February 2015), “heavy/moderate oiling” (where moderate or heavy oiling persisted for less than 12 weeks), “lighter oiling”, “no oil observed”, and “shoreline not surveyed” by linear shoreline evaluation methods. Of these sites, 187 along SCAT-surveyed shorelines were randomly chosen that represented the range of shoreline oiling categories. Vegetation along the majority of sites was classified as mainland herbaceous saltmarsh (primarily *Spartina alterniflora*, *S. patens*, or *Juncus roemerianus*) with some sites classified as mixed black mangrove (*Avicennia* *germinans*) and *Spartina* spp. or *Phragmites australis* dominated. Unsurveyed sites originally assigned to the "shoreline not surveyed" oiling category were excluded from further consideration.

Distribution of nearshore oysters

Following site selection, four field teams mapped oyster shell and other hard substrate over a total of 200 m of shoreline length at each of 187 sites. Each site was divided into 40 transects (20 on each side of a center location that was randomly chosen 0 to 5 m to the right of site center coordinates). Transects, which ran perpendicular to the shoreline, were 15 to 20 m in length (measured from the end of the vegetation line to offshore), and were spaced 5 m apart. Field teams cast a Y-shaped metal bar (secured to the end of a fiberglass meter tape) between 15 and 20 m from shore in a direction perpendicular to the shoreline and then slowly pulled it back along the sea floor, feeling for vibrations through the tape that would indicate the interaction of the bar with oyster shell. Transect lengths were measured beginning at the nearest meter mark on the tape.

Substrate along each meter of the 40 transects at a site was recorded as either type 1 (soft mud), 2 (moderately firm mud, firm mud or sand, and buried shell), or 3 (exposed shell or reef) for each meter of the transect. . The proportion of type 3 substrate cover, i.e., the percent cover of oyster shell for each mapped nearshore site was estimated as the total length (m) identified as type 3 substrate divided by the total length (m) mapped at that site.

We also examined the potential for response and oil clean-up activities that occurred on the shoreline to affect oyster cover. We reviewed records collected by NOAA related to shoreline oil spill response activities and classified each site as receiving onsite response treatment (if cleanup actions occurred within 200 m of sites) or not treated. Onsite response activities included placement of booms adjacent to shorelines to prevent oil from reaching shorelines; flushing marsh surfaces with water; cutting and raking marsh vegetation; removing wrack and vegetation; raking heavy oil deposits from soil surfaces; and, placement of loose sorbent material (Zengel et al. 2015). We did not attempt to separate treated areas by severity of disturbance because all onsite response activities would be associated with physical alteration of the soft-sediment habitat seaward of the marsh, and most onsite response activities would involve landing boats on the marsh edge and deploying crews at the sites.

Erosion/Shoreline Change

Prior to sampling nearshore oysters, several other NRDA studies were undertaken to evaluate exposure and injury to nearshore flora and fauna. Seventy-four nearshore oyster sampling stations were co-located with sites included in an evaluation of coastal wetland vegetation that collected synoptic data on shoreline erosion (Fig 1). The coastal wetland vegetation assessment (CWV) was intended to evaluate the effects of plant stem oiling on plant productivity, cover, and health and shoreline change (Hester et al.,2015). At each site, a transect was established with one to three fixed-location, permanent plot pairs (for observations and destructive sampling). The length of the initial transect was determined by the length of oil penetration into the vegetation with a maximum length of 30 m from the intersection of water and vegetation. For reference sites, at which no oil was observed, the default transect length was 20 m. The permanent location of the most shoreward plot pair was established with the shore edge of the plots located one meter from the marsh edge at the time of the first sampling event. Observations and measurements of shoreline change were made during each CWV sampling event. The length of the transect was first recorded when sites were established in the fall of 2010 (Louisiana sites) or the spring of 2011 (Mississippi and Alabama sites). At each subsequent survey (Spring 2011, Fall 2011, Fall 2012, Fall 2013), the distance from the inland stake to the marsh edge was measured, and observations of erosion or shoreline change were recorded. The 74 oyster sites that are co-located with the coastal vegetation sites are used here to evaluate relationships between oyster cover and shoreline change from the fall of 2010 to the fall of 2013.

Data analysis

For the purposes of evaluating nearshore oysters, we reduced the five shoreline oiling categories to three: heavy persistent oiling as defined above, oiled, and no oil observed. The heavy/moderate and lighter oiling categories were combined into an "oiled" category to distinguish effects of heavy persistent oiling, such as heavy fouling and smothering, from those sites that experienced more subtle effects of oiling (e.g., less physical fouling). ANOVA was used to determine the relationship between site oiling categories s and percent cover of nearshore oyster shell. Sites with and without any oyster cover were included in the analysis.

The effect of onsite shoreline response/oil cleanup activities on percent cover of oyster habitat in oiled sites was tested using an unpaired, two-tailed t-test assuming unequal variances. Treated sites were compared to untreated sites in the heavy persistent and oiling categories. We pooled treated and untreated sites across the two oiling categories to provide sufficient replication for the test.

To determine if the presence of oyster cover affected the erosion rate of adjacent vegetated marsh, we tested whether the presence/absence of oyster habitat as measured in the winter of 2013 is associated with lower site-specific annual shoreline erosion rate from the fall of 2010 to the fall of 2013 using an unpaired, one-tailed t-test assuming unequal variance. We define site-level oyster presence as ≥0.5% oyster cover.

Results/Discussion

Shoreline oiling and related cleanup actions significantly reduced cover of fringing oysters within 50 meters of marsh shorelines. Lowest percent cover values were recorded in areas adjacent to marshes that experienced heavy persistent oiling (2.3 ± 0.7 percent), followed by areas that experienced more moderate and less persistent oiling (6.9 ± 1.3 percent) and reference shorelines (10.3 ± 2.1 percent) (Figure 2). The proportion of sites with no oysters (with percent cover of oyster habitat <0.5 percent) was also highest adjacent to marshes that experienced heavy persistent oiling (56 percent), followed by lesser degrees of oiling (43 percent) and reference sites (24 percent). Average oyster densities by oiling category and oyster size class are presented in Roman (2015). Cleanup activities also affected percent cover of oyster habitat. For oiled sites with documented onsite or nearby cleanup activities, percent cover was significantly lower than oiled areas that did not have cleanup actions within 328 feet (100 meters) of sampling sites. The mean oyster percent cover at treated sites was 4.1 ± 0.9 percent compared to 10.1 ± 2.8 percent at untreated sites (Figure 3). The injury resulting from the *Deepwater Horizon* oil spill in summer of 2010 was largely a function of an acute disturbance that occurred during or within a year after the oil spill (assuming approximately 2 years for oyster growth from spat to market size). By destroying oyster cover through smothering or through physical destruction during cleanup activity, much less shell and hard surface remained for future larvae to settle on. Although the disturbance was relatively short-lived, the consequences of the losses to oysters are substantial, have no to very little predicted natural recovery, and include loss of essential fish habitat, reduced nutrient cycling and decreased shoreline stability.

In addition to directly contributing to elevation gain of marshes and bay bottoms through growth, shell production, and feces/pseudofeces production, oyster reefs also reduce shoreline erosion (Bahr and Lanier 1981). Shoreline erosion is reduced by the direct reduction in wave height and water current velocities by the friction of their rough, elevated rigid structure, as well as through the trapping of sediment and stabilization of marsh edge substrate. The analysis of injury to nearshore oysters found that shoreline loss was more than twice as high (2.9 versus 1.3 meters/year) in areas lacking nearshore oyster cover (a difference of 1.6 meters/year). The presence of nearshore oyster habitat was associated with significantly reduced shoreline erosion in the adjacent marsh (Figure 4). At two of the sites, erosion over the 3-year period was extremely high. If those sites are considered to be statistical outliers (more than 2 standard deviations above the mean) and removed from the analysis, the rate of excess erosion drops to 0.6 meters per year.

Seventy-nine nearshore oyster sampling stations were co-located with sites in Alabama, Mississippi, and Louisiana that included in an evaluation of coastal wetland vegetation that collected synoptic data on shoreline erosion. Because so little was known about nearshore oyster distribution before the spill, there was no pre-existing information about the likelihood of finding oyster cover at these sites, though they were all located within habitats and salinity conditions thought to be supportive of oyster presence. The confirmation that oysters would have been present in oiled areas comes from the distribution of oyster cover at reference (unoiled) sites and the fact that oiled and unoiled sites are similar in the factors necessary to support oysters and other factors that could enhance erosion.

Acknowledgements

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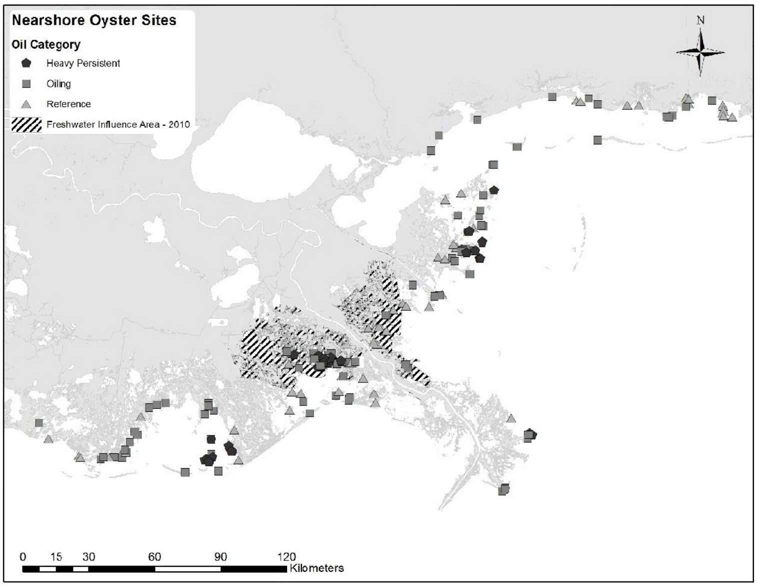

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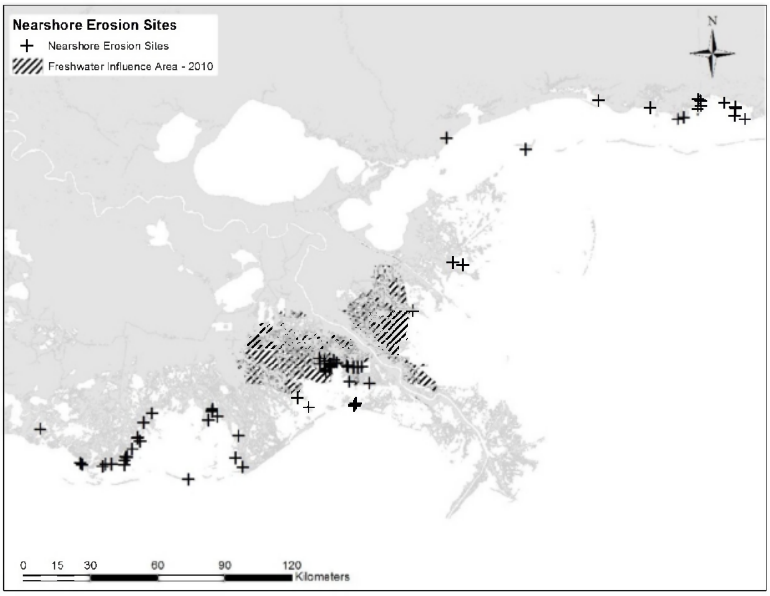

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Figure 1. Map of the northcentral Gulf of Mexico showing (A) the oiling category locations where nearshore oysters were sampled and (B) locations where shoreline erosion rates were documented.

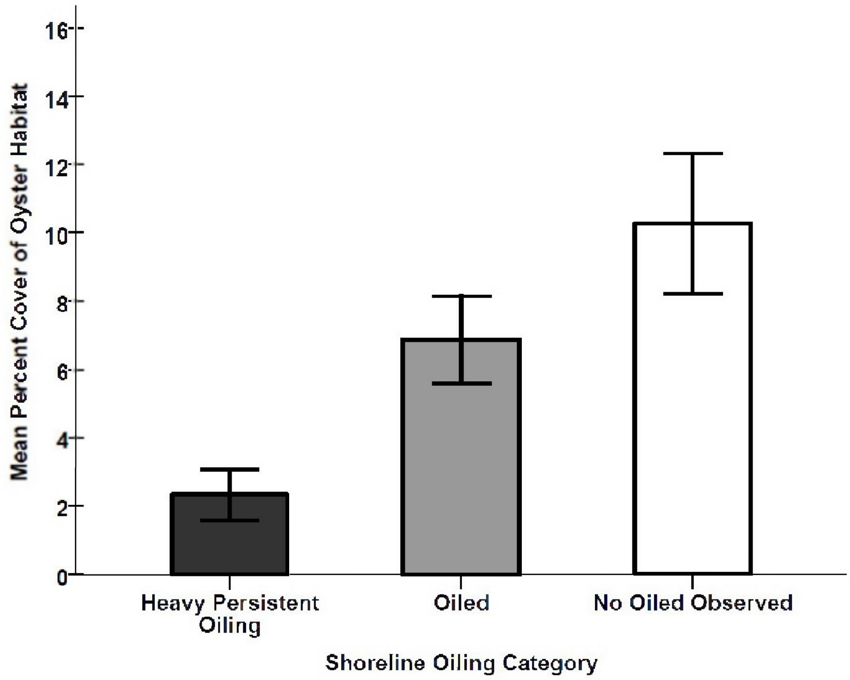

Figure 2. Mean percent cover ± 1 standard error of oyster habitat observed adjacent to vegetated shorelines with heavy persistent, moderate, and no oiling from Terrebonne Bay, LA to Mississippi Sound, AL. The percent cover of oyster habitat, for each mapped nearshore site was estimated as the total length (m) identified as type 3 substrate (exposed shell or reef) divided by the total length (m) mapped at that site.

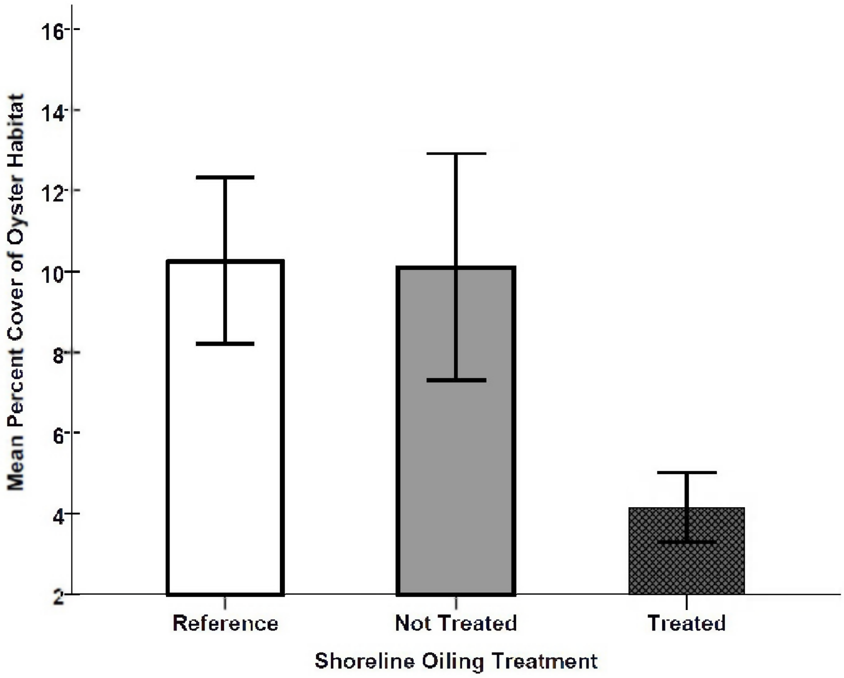

Figure 3. Mean percent cover ± 1 standard error of oyster habitat in heavy persistent oiling and oiled areas subject to response and clean-up activities (Treated) and where no activities occurred (Not Treated). Means are significantly different at $p < 0.05$. Mean percent cover ± 1 standard error for Reference sites is shown for reference only and was not included in the statistical analysis.

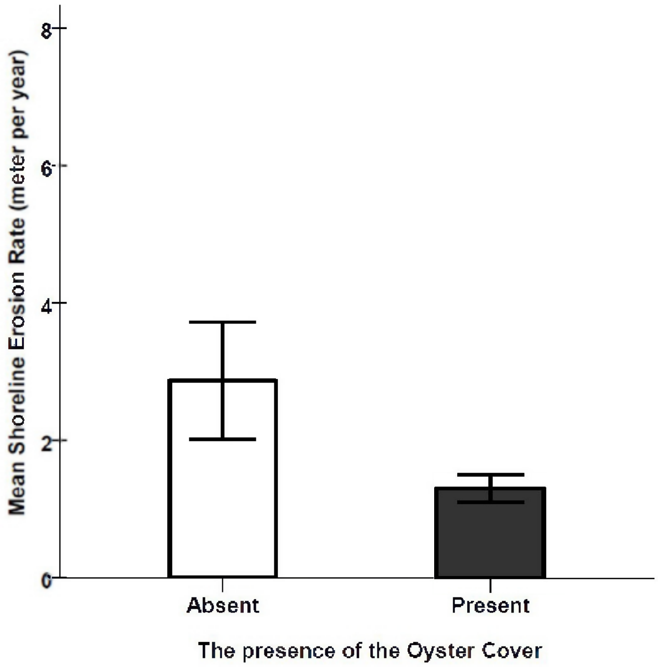

Figure 4. Mean ± 1 standard error of erosion rate (m loss per year) at sites with and without oyster habitat. Presence of oyster habitat defined as sites with ≥0.5% cover. Means were significantly different at $p < 0.05$.